Preprint
UCRL-JC-152300

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This article was submitted to
American Physical Society Topical Conference on Shock Compression of Condensed Matter
Portland, OR
July 20-25, 2003

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

July 1, 2003

THRESHOLD STUDIES OF HEATED HMX-BASED ENERGETIC MATERIAL TARGETS USING THE STEVEN IMPACT TEST

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Abstract. Impact tests performed at low velocity on heated energetic material samples are of interest when considering the situation of energetic materials involved in a fire. To determine heated reaction thresholds, Steven Test targets containing PBX 9404 or LX-04 samples heated to the range of 150-170°C were impacted at velocities up to 150 m/s by two different projectile head geometries. Comparing these measured thresholds to ambient temperature thresholds revealed that the heated LX-04 thresholds were considerably higher than ambient, whereas the heated PBX 9404 thresholds were only slightly higher than the ambient temperature thresholds. The violence of reaction level of the PBX 9404 was considerably higher than that of the LX-04 as measured with four overpressure gauges. The varying results in these samples with different HMX/binder configurations indicate that friction plays a dominant role in reaction ignition during impact. This work outlines the experimental details, compares the thresholds and violence levels of the heated and ambient temperature experiments, and discusses the dominant mechanisms of the measured thresholds.

INTRODUCTION

Low velocity impact tests (25-100 m/s), such as the Steven Impact Test, performed on heated energetic material samples are of interest when considering the situation of energetic materials involved in a fire scenario. In basic terms, the Steven Impact Test involves a target with High Explosives (HE) that you impact at increasingly higher velocities with projectiles until you get a "GO" (reaction). These reactions involve a burning or deflagration process in lieu of a full-scale detonation. Naturally, the lowest velocity where you get a "GO" is the "reaction threshold" and typically involves several experiments to determine. The secondary goal of obtaining thresholds is to incorporate them into hydrodynamic reactive flow models for accurate predictions and insight into similar safety scenarios that cannot be tested directly.

Experimental and reactive flow modeling research efforts using the Steven Impact Test at Lawrence Livermore National Laboratory [1-6] and a modified version of this test at Los Alamos National Laboratory [7-9] have greatly increased the fundamental knowledge and practical predictions of impact safety hazards for confined and unconfined explosive charges. The dominant microscopic mechanisms that control the initial ignition during compaction of a small volume of the explosive charge have been identified as friction, shear, and strain. However, the relative importance of these three processes in each ignition scenario has not yet been determined experimentally. It can be expected that heating the samples may change the relative importance of these mechanisms for impact ignition.

EXPERIMENTAL PROCEDURE

The experimental geometry of the Steven Impact Test target and details of the 2 different projectiles used is shown in Fig. 1. The 2 projectiles consist of different steel cylinders with impact surfaces of a hemispherical 30.05 mm radius and 6.365 mm "stubby nose" radius, respectively. Projectile #1 in Fig. 1 has a mass of 1.2 kg whereas projectiles #2 weighs 1.6 kg. The 1.6 kg mass was chosen because it is between the 1.2 kg of Projectile #1 and the 2 kg mass used in experiments by Idar et. al.[7]. A gas gun accelerates a test projectile into a 110 mm diameter by 12.85 mm thick explosive charge confined by a 3.18 mm thick steel plate on the impact face, a 19.05 mm thick steel plate on the rear surface, and 26.7 mm thick steel side confinement. A Teflon ring around the explosive provides radial confinement.

For these experiments, a 76 mm diameter smooth bore gas gun located at LLNL Site 300, bunker 812 was utilized and fires onto an outdoor firing table. The steel projectile heads (see Fig. 1) are attached to an aluminum sabot body that is accelerated via compressed helium gas into the target. External blast overpressure gauges were placed around the target at a 3.05 m standoff for direct comparison to the Susan test data [10].

Test targets made from PBX 9404 (94% HMX, 3% NC, 3% CEF) or LX-04 (85% HMX, 15% Viton) were heated in the range of 150-170°C with the use of "stove-top" spiral heaters placed at the front and rear of the target in addition to a cuff heater wrapped around the circumference. The front coil heater was configured to fall away from the impact surface just before firing the gun. The targets were allowed to soak at temperature for approximately one hour before impact.

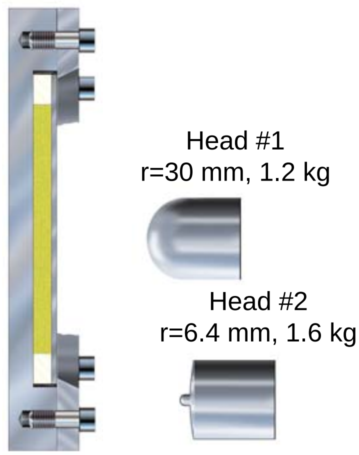

FIGURE 1. Schematic diagram of the standard Steven Impact Test arrangement with two different projectile heads used in this work. Note that the "stove-top" coil heaters at front and rear of target as well as the cuff heater around diameter of the target used for heating are not shown.

RESULTS/DISCUSSION

The tabulated results for this work are included in Tables I and II for projectile heads #1 and #2 respectively. Included are details of HE sample type, sample density, stockpile age, threshold velocity, and measured over-pressure. For projectile head #1, it can be seen that the heated threshold for PBX 9404 is slightly higher than that for ambient temperature, whereas the LX-04 heated threshold is considerably higher. The actual LX-04 threshold is not known due to lack of reaction in tests performed. An important detail is that the heated PBX 9404 was tested at 165°C because it thermally exploded at the 170°C test temperature at approximately 40 minutes during the hour-long soak period. For projectile head #2, it can be noticed that the heated PBX 9404 thresholds are again slightly higher than those of ambient PBX 9404. The heated LX-04 thresholds are also higher, but only by a factor of approximately 2.

Comparing the two tables shows that the threshold impact velocity of the HE is dependent on the shape of the projectile's impact surface and test temperature. The LX-04 samples appear to show a more dramatic difference to the projectile shape than the PBX-9404 samples. One detail that stands out in this comparison is the increased violence (high overpressure) for heated PBX 9404 using both projectile head configurations.

The varying results in these samples with different HMX/binder configurations indicate that friction plays a dominant role in reaction (ignition) during impact. Recovery of unreacted LX-04 for the projectile #1 showed the extrusion of the HE "disk" into a "ring" geometry (~98% of the sample weight recovered). Because of the high binder percentage (15 wt% Viton), it appears that free flow of the material occurs upon impact, which between the HE and metal surfaces minimizes friction. With reaction of the LX-04 at approximately 65 m/s with head #2, it appears that the head geometry acts to pin some of the material under the "stubby nose," allowing for initiation of reaction. The known effect of stockpile aging of the nitrocellulose (3 wt %) in PBX 9404 may be a contributor to the excessive violence that is seen, although pristine heated samples were not tested for comparison. One salient point taken from these comparisons could be that not all conventional HE's necessarily behave alike.

TABLE I. Heated results for projectile Head #1.

HE TYPE	DENSITY (g/cc)	STOCKPILE AGE (MONTHS)	TEST TEMP (°C)	THRESHOLD VELOCITY (m/s)	AVERAGE OVER PRESSURE (psi)
PBX 9404	1.835	0	20	34.0 (+0, -3.0)	3.1
PBX 9404	1.844	272	20	36.0 (+0, -2.0)	3.5
PBX 9404	1.845	408	20	35.7 (+0, -1.2)	3.2
PBX 9404	1.844	390	150	50.5 (+0, -3.5)	1.5
PBX 9404	1.844	390	165*	47.2 (+0, -2.9)	11.8
LX-04	1.870	0	20	45.0 (+0, -5.0)	0.2
LX-04	1.865	270	20	43.0 (+0, -3.0)	0.4
LX-04	1.866	255	150	>125.7	NA**
LX-04	1.866	255	170	>153.2	NA**

*The PBX 9404 thermally exploded at 170°C 40 minutes into the 1 hour soak time.
**The LX-04 at 150 & 170°C would not react when impacted with projectile 1 at velocities up to 153 m/s.

TABLE II. Heated results for projectile Head #2.

HE TYPE	DENSITY (g/cc)	STOCKPILE AGE (MONTHS)	TEST TEMP (°C)	THRESHOLD VELOCITY (m/s)	AVERAGE OVER PRESSURE (psi)
PBX 9404	1.835	0	20	29.1 (+0, -2.3)	3.1
PBX 9404	1.844	390	150	48.8 (+0, -2.1)	3.6
PBX 9404	1.844	390	165*	48.2 (+0, -1.9)	10.2
LX-04	1.870	0	20	30.7 (+0, -0.9)	0.3
LX-04	1.865	270	20	30.5 (+0, -0.4)	0.4
LX-04	1.866	255	150	64.8 (+0, -7.1)	0.4
LX-04	1.866	255	170	64.7 (+0, -4.9)	0.4

*The PBX 9404 thermally exploded at 170°C 40 minutes into the 1 hour soak time.

SUMMARY AND FUTURE WORK

Steven Test targets containing PBX 9404 or LX-04 samples heated to the range of 150-170°C were impacted at velocities up to 150 m/s by two different projectile head geometries. Comparing these measured thresholds to ambient temperature thresholds revealed that the heated LX-04 thresholds were considerably higher than ambient, whereas the heated PBX 9404 thresholds were only slightly higher than the ambient temperature thresholds. The violence of reaction level of the heated PBX 9404 was considerably higher than that of the LX-04 as measured with four overpressure gauges. The results appear to place emphasis on friction as a dominant reaction mechanism in these heated tests.

Future work is planned in the area of applying these results into computer models for making necessary predictions. Expanding these results to include testing on the explosive PBX 9501 is also desired.

ACKNOWLEDGEMENTS

The following members of the 76 mm gun crew at Site 300 (Bunker 812) are thanked (especially main crew) for their hard work: Karen Luis, Don Gonzalez, and Brad Wong who make up the main crew and John Given, Fred Sator, Tommy Rambur, and Mike Wagoner as bunker supervisors. Funding for this research provided through the Defense Technologies Engineering Division (DTED) at LLNL is greatly appreciated. This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

REFERENCES

1. Chidester, S.K., Green, L.G., and Lee, C.G., “A Frictional Work Predictive Method for the Initiation of Solid High Explosives from Low Pressure Impacts,” Tenth International Detonation Symposium, ONR 33395-12, Boston, MA 1993, pp. 785-792.
2. Chidester, S. K., Tarver, C. M., and Lee, C. G., “Impact Ignition of New and Aged Solid Explosives,” Shock Compression of Condensed Matter-1997, edited by S.C. Schmidt et. al., AIP Conference Proceedings 429, AIP Press, New York, 1998, pp. 707-710.
3. Chidester, Steven K., Tarver, Craig M., and Garza, Raul, “ Low Amplitude Impact Testing and Analysis of Pristine and Aged Solid High Explosives,” Eleventh (International) Symposium on Detonation, ONR 33300-5, Arlington, VA, 1998, pp. 93-100.
4. Chidester, S. K., Tarver, C. M., DePiero, A. H., and Garza, R. G., “Single and Multiple Impact of New and Aged High Explosives in the Steven Impact Test,” Shock Compression of Condensed Matter-1999, M.D. Furnish, L. C. Chhabildas, and R. S. Hixson, eds., AIP Conference Proceedings 505, New York, 2000, P. 663-666.
5. Niles, A. M., Garcia, F., Greenwood, D. W., Forbes, J. W., Tarver, C. M., Chidester, S. K., Garza, R. G., and Switzer, L. L., “Measurement of Low Level Explosives Reaction in Gauged Multi-dimensional Steven Impact Tests,” Shock Compression of Condensed Matter-2001, Furnish, M. D., Thadhani, N. N., and Horie, Y, eds. CP-620, AIP Press, New York, (2002).
6. Kevin S. Vandersall, Steven K. Chidester, Jerry W. Forbes, Frank Garcia, Daniel W. Greenwood, Lori L. Switzer, and Craig M. Tarver, “Experimental and Modeling Studies of Crush, Puncture, and Perforation Scenarios in the Steven Impact Test,” Proceedings of the 12th International Detonation Symposium, San Diego, CA, August, 2002, in press.
7. Idar, D. J., Lucht, R. A., Straight, J. W., Scammon, R. J., Browning, R. V., Middleditch J., Dienes, J. K., Skidmore, C. B., and Buntain, G. A., Eleventh International Detonation Symposium, Aspen, CO, 1998, pp. 101-110.
8. Scammon, R. J., Browning, R. V., Middleditch, J., Dienes, J. K. Haverman, K. S., and Bennett, J. G., Eleventh International Detonation Symposium, Aspen, CO, 1998, pp. 111-118.
9. Browning, R. V., in Shock Compression of Condensed Matter-1995, S. C. Schmidt and W. C. Tao, eds, AIP Press, New York, 1996, p. 405-408.
10. Dobratz, B.M. and Crawford, P.C., LLNL Explosives Handbook, Lawrence Livermore National Laboratory Report UCRL-52997 change 2, 1985.